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For

TECHNIQUE FOR STABILIZING LASER WAVELENGTH AND PHASE

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A TECHNIQUE FOR STABILIZING LASER WAVELENGTH AND PHASE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part of U.S. patent application number 10/425,279, filed April 28, 2003, and claims priority thereto under 35 U.S.C. § 120.

FIELD

[0002] Embodiments of the invention relate to laser technology. More particularly, embodiments of the invention relate to stabilizing a light's wavelength or phase across multiple wave guide temperatures by using materials within the wave guide having varying temperature reaction characteristics.

BACKGROUND

[0003] Laser systems use focused, intense light rays of a particular wavelength or wavelength range that may be used in various applications, including data storage, medicine, semiconductor processing, and network communications. The light used in laser systems, however, can be sensitive to temperature variations among structures within the laser generating system. This is due, at least in part, to temperature sensitivity of light refraction indices in various materials used within the laser generating system.

[0004] Figure 1 illustrates a prior art system for generating a light in a laser system. The light is generated and amplified by a semiconductor optical amplifier (SOA) chip 101. The light generated by the SOA enters a wave guide

105 consisting of a clad material 110, such as silicon dioxide or other material with a lower refractive index than the core, a wave guide core 115, and series of grating elements 120 (grating) that help to direct and refine the light toward a desired wavelength and phase. After light enters the wave guide, it is passed through the grating, which can refine the character of the light, including the light's wavelength.

[0005] One way in which the grating can refine the wavelength of the light is to reflect certain wavelengths in the light and propogate others. Particularly, the grating can refine the light's wavelength by reflecting the undesired wavelengths of the light from the grating toward the SOA chip where the light can be amplified and re-direct toward the grating. Moreover, a desired light phase can be produced by placing the grating a certain distance from the SOA chip, such that the round trip distance of the reflected light is an integer division of the desired wavelength.

[0006] Unfortunately, the wave guide clad material and the wave guide core material can change temperature during the course of generating and refining the light, which can, in turn, change the refraction indices of the wave guide core and clad materials. The refraction index of a material is an indicator of the material's ability to pass or reflect certain frequencies of light. As the refraction index of the clad or core material changes with temperature, less of a particular wavelength of light may be reflected and therefore propagated through the wave guide, resulting in loss of light intensity or a change in the light's wavelength.

[0007] As a light travels through the wave guide core, it can be effected by the overall effective refraction index of a substantially cylindrical area surrounding the wave guide core known as the optical mode. Figure 2 illustrates a cross-sectional view of the wave guide, in which the cross-section of the optical mode is circumscribed by the circle 201. The material within the boundary of the optical mode can effect the light traveling through the core if the temperature of the material changes, due to the resulting change in the refraction index of the material within the optical mode.

[0008] Adverse effects on the light due to temperature sensitivity of refraction indices of materials has been addressed in some prior art laser generating systems by using power-consuming devices, such as a thermal electric cooler (TEC). The TEC may be used to cool the wave guide within the optical mode as the wave guide temperature increases from the laser generation process. Through, what can be, an elaborate technique of detecting the optical mode temperature and adjusting the TEC accordingly, the temperature of the wave guide in the optical mode can remain stable enough to generate a light that is substantially the desired wavelength and phase for a particular application.

[0009] The TEC, however, can have adverse effects on system power consumption, system cost, and system reliability. Furthermore, the accuracy of the light's wavelength and phase, using a TEC, is, at least in part, a function of how quickly the TEC can respond to temperature variations within the optical mode without over-compensating for those variations. As a result, the overall accuracy of the light can be compromised.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Embodiments of the invention are illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

[0011] Figure 1 illustrates a prior art laser generating system.

[0012] Figure 2 illustrates an optical mode within a prior art laser generating system.

[0013] Figure 3 illustrates a laser generating system according to one embodiment of the invention, in which a polymer is added to the wave guide.

[0014] Figure 4 illustrates a cross-sectional view of a laser generating system according to one embodiment of the invention in which a polymer exists within the optical mode on opposite sides of the wave guide.

[0015] Figure 5 illustrates a cross-sectional view of a laser generating system according to one embodiment of the invention in which a polymer exists within the optical mode on one side of the wave guide.

[0016] Figure 6 illustrates a laser generating system according to one embodiment in which a phase is substantially maintained across temperature variances.

DETAILED DESCRIPTION

[0017] Embodiments of the invention pertain to the generation of a light of a desired wavelength and phase. More particularly, embodiments of the invention pertain to using certain materials within the wave guide of a laser generation system, such that the refraction indices of the materials contribute to an overall substantially constant effective refraction index of the optical mode of the wave guide, which is largely independent of temperature variations.

[0018] Stabilization of a light wavelength within a laser generating system can be achieved more reliably, accurately, and inexpensively than in many prior art techniques by introducing a material into the wave guide clad that has inverse refraction characteristics to those of the clad material across temperature variances.

[0019] For example, the refraction index of the clad material may increase with temperature, thereby causing the overall effective refraction index of the wave guide within the optical mode to increase, which may then effect the wavelength, intensity, or other characteristics of the light produced. Adding a material to the wave guide within the optical mode whose refraction index decreases with increasing temperature can help to counter this effect, creating an overall effective refraction index within the optical mode that is substantially the same across varying temperatures.

[0020] Figure 3 illustrates one embodiment of the invention in which a polymer is added to the wave guide clad material in order to offset the effect of temperature-induced refraction index changes of the clad material within the

optical mode. In Figure 3, a polymer 301 exists anywhere throughout the grating area 305 in order to stabilize the effective refractive index of the clad 310 across the grating region. This is but one example, however, of where the polymer may be placed within the clad in order to have the desired effect. Furthermore, the polymer may be placed throughout the clad in various positions and quantities depending upon the clad material used and the particular design needs of the laser generating system.

[0021] A light's wavelength is stabilized across varying clad temperatures in at least one embodiment of the invention, by using appropriate proportions of clad material and polymer within the optical mode of the wave guide.

[0022] Figure 4 illustrates a cross section of a wave guide according to one embodiment of the invention, in which the polymer and clad material exist within the optical mode of the wave guide in suitable proportions to have the desired stabilizing effect. The cross-sectional area of the polymer 401 that exists within the optical mode 403 in order to effectively offset the temperature-induced variations of the refraction index of the clad material 405 is determined in the embodiment illustrated in Figure 4 by the equation:

$$n_{eff,grating} = \frac{n_{polymer} \cdot a_{polymer} + n_{core} \cdot a_{core} + n_{clad} \cdot a_{clad}}{a_{polymer} + a_{core} + a_{clad}}$$

[0023] In the above equation, the effective refraction index within the grating region is a function of the multiplicative product of the refractive indices ($n_{polymer}$, n_{core}, and n_{clad}) of the various materials within the optical mode and the areas ($a_{polymer}$, a_{core}, and a_{clad}) of the optical mode that they occupy.

[0024] In other embodiments of the invention, other methods of determining the proportion of clad, core, and polymer and their relative positions in the optical mode in order to stabilize the effective refraction index of the laser generating device may be used. For example, Figure 5 illustrates one embodiment of the invention in which the polymer exists on only one side of the core. However, the proportion of areas of core 510, polymer 501, and clad 505 within the optical mode 515 are such that the above equation is satisfied.

[0025] The desired wavelength that is passed by the grating in the embodiment illustrated in Figure 4 is determined by the equation:

$$\lambda_0 = n_{eff,grating} \cdot \Lambda$$

[0026] In the above equation, the effective grating refraction index at the grating region is multiplied by the period of the grating, denoted by the upper-case lambda. The period of the grating is determined in part by the periodic modulation of the portion of the optical mode's effective refraction index that surrounds the grating length. Within the length of the grating, one half of the period of the light that passes through it has a slightly higher index than the other half due to the changing effective refraction index from one end of the grating to the other. Because of this small index difference, each lens of the grating behaves like a weak mirror, partially reflecting the light as it passes through. Therefore, the period of the grating is a function of the thickness of each lens.

[0027] In addition to the wavelength of the light, the phase of the light may be adversely effected by temperature changes within the optical mode of the wave

guide. This effect can occur, for example, if the refraction index changes within the optical mode of the portion of the wave guide in which the light is reflected by the grating. For example, if the round-trip optical length of a photon (quantum of the light's energy embodied in a range of wavelengths) of the light that reflects back from the grating to the light source does not have a wavelength that is an integer division of the desired light wavelength, then destructive effects can occur to the desired light photon.

[0028] Figure 6 illustrates a laser generating system according to one embodiment of the invention, in which a polymer segment has been introduced to the clad material of the wave guide between the SOA chip and the grating. The polymer segment 601 extends into the optical mode of the wave guide enough to satisfy the above equations relating to wavelength stability and is of an appropriate length along the wave guide core to create a stable light phase that is substantially independent of temperature variations.

[0029] A desired optical round trip distance traveled by the photons reflected back to the SOA chip from the grating is maintained in the embodiment illustrated in Figure 6 by choosing relative lengths of the clad material segments and the polymer segments that satisfy the following equation:

$$2\cdot(n_{eff,SOA}\cdot L_{SOA}+n_{eff,L1}\cdot L1+n_{eff,phase}\cdot L_{phase}+n_{eff,L2}\cdot L2+n_{eff,grating}\cdot L_{grating}/2)=m\cdot\lambda_0$$

[0030] In the above equation, the summation of the multiplicative products of the refraction indices of the various segments between the SOA chip and the grating ($n_{eff,\,SOA}$, $n_{eff,L1}$, $n_{eff,\,phase}$, $n_{eff,\,L2}$, and $n_{eff,\,grating}$) and the lengths of the respective segments (L_{SOA}, L_{L1}, L_{phase}, L_{L2}, and $L_{grating}$) 602, 603, 604, 605, 606

are a constant integer multiple (m) of the desired light wavelength 607. The entire sum is multiplied by two to account for the round trip of the light photon. In other embodiments, other methods of determining the length of clad, core, and polymer segments in order to stabilize the effective phase of the laser generating device may be used. For example, in at least one embodiment of the invention, L_{L1}, L_{phase}, and L_{L2}, may be represented by one or two lengths encompassing the the sum of L_{L1}, L_{phase}, and L_{L2}. Furthermore, one or more of the these segment lengths may be represented by multiple segment lengths in other embodiments of the invention.

[0031] Also illustrated in Figure 6 is a graph 608 showing the emission spectrum power of the SOA chip and a graph 609 showing the reflectivity percentage of the grating at various wavelengths along the light spectrum, according to one embodiment of the invention. The graph 609 indicates that the grating effectively passes the highest power spectral range of the light and reflects the rest in at least one embodiment of the invention.

[0032] Although a polymer is used in the above embodiments of the invention, other materials may be used in addition to or instead of the polymer that possess refraction indices suitable to stabilize the effective refraction index and/or phase of a particular clad material. Furthermore, the distribution, concentration, and position of the polymer or other material(s) are different in other embodiments depending in part upon the physical characteristics of the clad and the laser generating system. Similarly, the SOA chip is only one example of a light source that may be used with embodiments of the invention. Other light sources,

including those integrated within the wave guide, may be used in other embodiments of the invention.

[0033] While the invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications of the illustrative embodiments, as well as other embodiments, which are apparent to persons skilled in the art to which the invention pertains are deemed to lie within the spirit and scope of the invention.